Digital Wattmeter Element for the Bird Model 43 Wattmeter

Long a mainstay in amateur radio shacks, the Bird Model 43 Wattmeter has one very important weakness—the analog meter. Here WA8SME describes how he replaced the rather pricey meter with a digital meter element he designed and built for his Model 43.

By Mark Spencer,* WA8SME

My Bird Wattmeter is tied for second place as my most important and most used piece of test equipment. First place, hands down, goes to my voltmeter; my MFJ Antenna Analyzer shares the second place slot with the wattmeter; and my oscilloscope comes in third.

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The wattmeter has been an invaluable asset in installing and maintaining my satellite ground station antenna system. It is rugged, reliable, and fairly easy to use except that you have to enter the forward and reflected watt readings into a formula to calculate the VSWR. This really isn't that big a deal and keeps the dust off the gray matter. However, I did have a friend who dropped his wattmeter and broke the analog meter element. That got me thinking: How much would it cost if my meter experienced the same fate? Wow . . . around 150 bucks to replace the analog meter movement!

That thought was the catalyst for the project detailed here, a replacement or add-on digital meter element that could more affordably bring a broken Bird Wattmeter back to life and do some of the SWR and power-loss calculations for me. The digital wattmeter element is designed to actually replace the analog meter element inside the Bird or be mounted in an external enclosure to augment the standard Bird (figures 1 and 2).

The digital wattmeter element is based on a PIC®16F688 microcontroller and an inexpensive LCD display module. Refer to the circuit diagram of figure 3 for the following discussion of the circuit. The digital wattmeter element is powered by a 9-

Figures 1 & 2. The digital wattmeter element is designed to either replace the analog meter element inside the Bird Wattmeter (left) or be mounted in an external enclosure to augment the standard Bird (below).

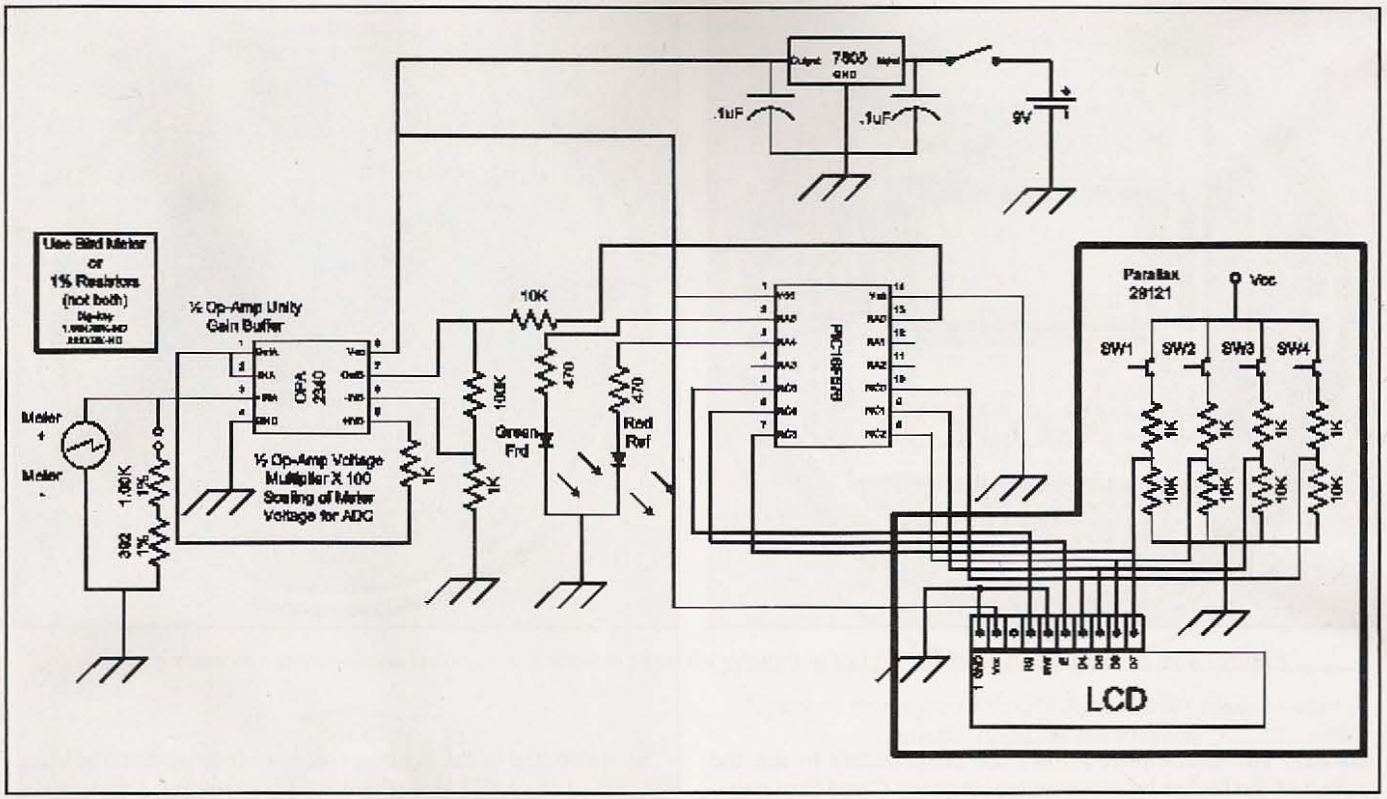


Figure 3. Alternate Bird Wattmeter meter element circuit diagram.

volt battery with the voltage stepped down and regulated to 5 volts by one half of the OPA2340.

The op amp is configured as a unity-gain buffer between the Bird Wattmeter and the digital wattmeter element circuit. The OPA2340 op amp requires a single voltage source, and this simplifies the circuit (at some added cost for the device). The input precision resistors that are shown in parallel with the analog meter are inserted into the circuit by a jumper. These resistors are required in the circuit to replace the resistance of the analog meter element if the digital meter will replace the analog meter, but they are not required if the digital meter will be used in conjunction with the analog meter. The other half of the op amp is configured as a times-100 voltage multiplier. The voltage across the analog meter (or the precision resistors) is on the order of 40 mV at full scale. The voltage multiplier boosts this voltage to approximately 4 volts to make it easier to measure with the PIC analog to digital (ADC) circuit.

The PIC is programmed to read the voltage from the wattmeter with the on-board 10-bit ADC, scale and calculate the watts being sensed (forward or reflected), calculate the SWR and power loss, and display the data on the LCD. A more detailed explanation of the programming logic will follow shortly. The final component of the circuit is the LCD module which includes a two-line eight-character LCD display and four momentary switches for user input, all in one convenient package. Two LEDs round out the circuit and provide a visual indication when forward power (green LED) or reflected power (red LED) is being measured in real time.

The prototype of the digital wattmeter element mounted in the Bird analog meter mounting ring is shown in figures 4 and 5.

Using the PIC ADC to measure the voltage produced by the wattmeter during operation is fairly straightforward. However, the correlation between voltage and watts is not a linear function, and this makes the mathematical conversion a bit more complicated. Figure 6 is the graph that shows the relationship between the measured watts and the ADC values. I used graphing calculator technology to do a curve fit of the watts to ADC graph, and then in turn used the resulting function in the PIC program to calculate the watt value from the measured ADC value. The curve fit function is:

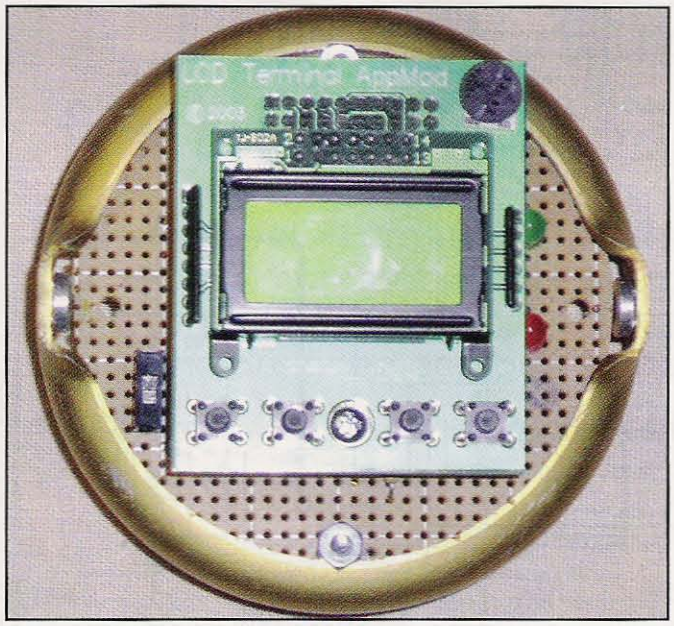
$$\text{watts} = 4.988 \times 10^{-6}\ \text{ADC}^2 = 1.652 \times 10^{-3}\ \text{ADC} + 0.00538$$

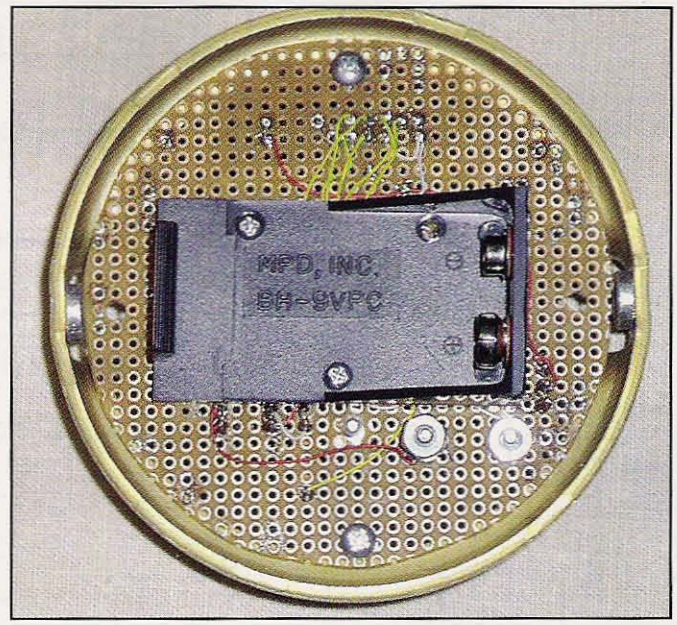
With a calculated value for watts, the PIC software continues by calculating the VSWR and power loss using the following formulas:

$$\text{VSWR} = \frac{1 + \sqrt{\frac{\text{Watts}_{Ref}}{\text{Watts}_{For}}}}{1 - \sqrt{\frac{\text{Watts}_{Ref}}{\text{Watts}_{For}}}}$$

$$\text{loss}_{dB} = -10\log\left(\frac{\text{Watts}_{For} - \text{Watts}_{Ref}}{\text{Watts}_{For}}\right)$$

I generally program PICs using assembly language. However, these formulas would have been a pretty daunting challenge to program in assembly. A C-compiler was the





Figures 4 & 5. The prototype of the digital wattmeter element mounted in the Bird analog meter mounting ring.

answer. The C-compiler allows the programmer to use the power of the higher level computer language C and then translates the C code into assembly and machine language code that is used by the PIC. Unfortunately, these hefty formulas require a lot of computer memory space to store and execute the code. I prefer to use PICs that have 2 kilobytes of memory (for cost reasons, and also most of my projects do not require a lot of memory), but in this case more memory was needed (approximately 6 kilobytes) and the PIC16F688 has this amount of memory (with a modest increase in cost of a buck or two).

The best way to go through the program logic is to describe how the digital meter element is used in operation. When power is first applied to the digital meter element, the PIC and the LCD are initialized, the previous scaling factors used are recalled from EEPROM, and the meter defaults to reading forward power. The green LED illuminates and the digital meter is ready to go.

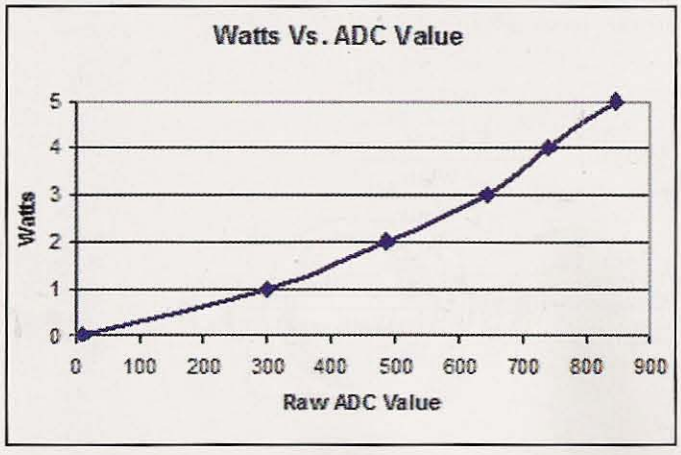


Figure 6. Graph that shows the relationship between the measured watts and the ADC values.

As illustrated in the figures, there are four pushbuttons that are part of the LCD unit (I'll label them buttons 1 through 4, from left to right, for this discussion). The two middle buttons (2 and 3) are programmed to select either reflected or forward power as the active wattage being measured. When first turned on, the display will have 0000.00 F (for zero watts forward) on the first line of the LCD, and an R (for reflected) on the second line. The green LED will also be illuminated as a visual indicator of forward power. There may be some random noise on the ADC that will give non-zero wattage indications when power is not applied to the Bird Wattmeter. When you press button 2, the digital meter element will switch over to measuring reflected power, the green LED will extinguish, the red LED will illuminate, the last forward watt reading will remain on the top line of the LCD, and the reflected power will be displayed on the second line of the LCD. To revert to measuring forward power, press button 3, the red LED goes out, the green LED comes on, the last reflected power read remains displayed on the second line of the LCD, and the current forward power is displayed on the top LCD line.

The Bird uses interchangeable slugs that are calibrated for frequency and power, and then the slug is rotated in its directional socket on the front of the Bird to measure forward or reflected power. The Bird analog meter has three scales that are applied during reading and/or calculations depending on the power of the slug in use: 0 to 100 for 10-, 100-, and 1000-watt slugs; 0 to 50 for 5-, 50-, and 500-watt slugs; and 0 to 25 for 25- and 250-watt slugs. The digital wattmeter element needs to be set to the appropriate scaling to display and make accurate calculations. The right-hand pushbutton (4) on the LCD unit is programmed to toggle through the various slug watt values when pressed by the user. When button 4 is pressed, the watt scale for both forward and reflected readings is displayed on the appropriate line of the LCD. Holding button 4 will step through the various scaling factors for the active channel (forward or reflected); release the button when the desired scaling factor is reached. This value is stored in EEPROM of the PIC

Figure 7. While applying power to the wattmeter, press button 1 to calculate the VSWR and power loss. The top line of the LCD will display the SWR and the second line will display the power loss in dB.

and is retrieved when the digital meter is subsequently powered-up. Press the appropriate button to select the other measurement channel to set its scaling factor. During my typical operating, I use the 100-watt slug to measure forward power and the 5-watt slug to measure reflected power, so these are the scaling factors that I use most frequently.

After you have the scaling factors set up, you're ready to take some SWR readings. Have the appropriate slugs on hand. I'll illustrate with the 100- and 5-watt slugs. Install the 100-watt slug and rotate it to the forward direction. Turn on the digital meter element. Apply power to the Bird Wattmeter and the forward power will be displayed. While the forward power is being displayed, press button 2 to switch the digital meter element over to reflected power (the forward power is now stored and displayed on the LCD). Turn off the transmitter RF. Swap out the slug to the 5-watt slug and rotate it in the reflected direction. Again apply transmitter power to the Bird Wattmeter and the reflected power will be displayed on the LCD. While applying power to the wattmeter, press button 1 to calculate the VSWR and power loss. The top line of the LCD will display the SWR and the second line will display the power loss in dB (figure 7). When you release button 1, the digital meter element will revert back to measure reflected power.

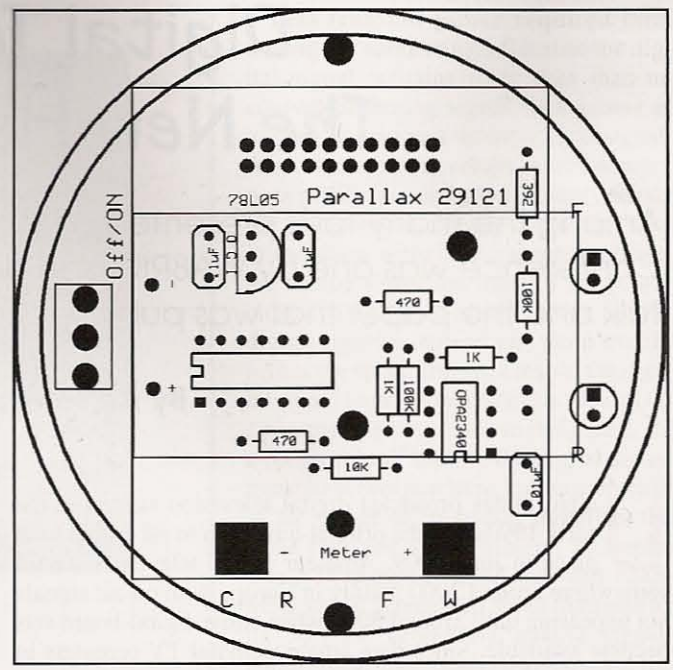


Figure 8. Prototype of the PCB the author plans to have manufactured for the project.

Some of you may be concerned with the accuracy of the digital meter element, and this is a legitimate concern considering all the conversions of voltages to ADC values, converting integers to float values and back again, curve fitting, and all the calculations going on and the rounding errors that result. Using the PIC and doing the calculations with limited variable sizes does introduce some rounding errors, but frankly so does using your eyes to read an analog meter. I have found that the digital meter element is about as accurate as using the eyeball and calculator. You just have to recognize that even though the digital meter element will display numbers to two decimal places that does not necessarily mean that the displayed results are accurate to the hundredth.

Summary

This little project has turned out to be pretty useful. I plan to get a PCB manufactured for the project to make it more professional looking and more rugged. Figure 8 illustrates what I have in mind. The final cost of the digital wattmeter element turns out to be a fraction of the cost of a replacement analog meter. The addition of the calculated VSWR and loss figures is a nice feature. I encourage you to consider duplicating this circuit to enhance your Bird Wattmeter, repair your Bird, or put into service that good deal on a broken Bird you got at the last hamfest. I will conclude with a bad pun intended, "A Bird in the hand..." Well, you know what I mean.

If you would like more information about this project, feel free to contact me at <mspencer@hughes.net>.